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A statistical analysis for micro-simulation of UDC operativity

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Abstract

An Urban Distribution Center (UDC) is a useful City Logistics policy instrument. A UDC is a logistic site dedicated to decompose and consolidate freight directed to the city, by planning the routes and service time, restricting the traffic of trucks and increasing the load factor of feeder vehicles. A UDC can produce interesting impacts on the dynamics of urban freight distribution, but its success depends on many factors: an appropriate location; a well-balanced presence of spaces and equipment; an efficient and effective organization of internal services; a connection with the surrounding area and with the related transport services; a management structure that meets different and complementary requirements; a capacity to support itself. The paper proposes an analysis of the functional organization of a UDC through a “what if” micro-simulation approach aimed at the UDC efficiency control. After a review of the state of the art, a procedure to implement a discrete-event micro-simulation model is described. Probability functions concerning the times of UDC activities are proposed.

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Keywords:UDC; simulation model; efficiency; probability function

1. Introduction

A UDC can be defined as "*a logistic platform for the centralized management of takings and deliveries, which is aimed at goods distribution in an urban area through the aggregation of freight flows and the optimization of routes*" (Da Rios and Gattuso 2003). In other words, a UDC is a logistic platform of cross-docking where goods directed to an urban area are received and distributed and groupage / degroupage activities are carried out. In literature, the problems related to the management/optimization of cross-docking terminals are dealt with from two different points of view (Table 1).

In the first case (approach A), the management problems are analyzed in a global context in order to

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plan, optimize and control the operations of the whole terminal. In this case, it is possible to carry out an integrated analysis of the system and to obtain tactical/strategic evaluations. In the second case (approach B), the study context is precise and includes resource scheduling and allocation as well as system evaluations with a high level of disaggregation and strategic operative evaluations.

Table 1. Approaches to UDC management

	Approach A	Approach B
Study context	Global	Punctual
Analysis type	Technical/economic	Resource scheduling/allocation
System evaluation	Aggregate	Disaggregate
Strategic evaluation	Tactical/Strategic	Operative

Table 2 shows a review of sector studies about the management problems of a cross-docking terminal. The adopted method (traditional, heuristic or simulation), the model type and the utilized solution technique are specified in the table.

Table 2. Sector literature

	Year	Author	Method	Model	Resolutive Technique
Approach A	2004	Li et al.	Heuristic	Integer program	Genetic algorithm
	2005	Magableh et al.	Simulation	Microscopic, discrete, dynamic, stochastic	SW ARENA
	2008	Boysen et al	Heuristic	Dynamic program	Heuristic procedure
Approach B	1999	Tsui and Chang	Traditional	Bi-linear program	Branch & Bound
	2006	Adewunmi and Aickelin	Simulation	Microscopic, discrete	
	2008	Bozer and Carlo	Heuristic	Mixed Integer program	Simulated annealing
	2008	Vis and Roodbergen	Heuristic		Heuristic procedure
	2008	Adewunmi and Aickelin	Simulation	Microscopic, discrete	
	2009	Rong Zhu et al.	Traditional	Linear program	
	2009	Liu and Takakuwa	Simulation	Microscopic, discrete, dynamic, stochastic	SW ARENA
	2010	Boysen	Heuristic	Dynamic program	Heuristic procedure

Li et al. (2004) dealt with the problem of the optimization of cross-docking internal activities in order to reduce picking and storage activities. The problem of scheduling node activities was dealt with as a machine scheduling problem: every inbound and outbound cargo unit was a “work” that had to be processed by teams. These teams could be compared to machines operating simultaneously. Magableh et al. (2005) used a discrete-event micro-simulation model to evaluate, in a dynamic way, the risks connected to node activities. Moreover, they proposed the analysis of demand growth. Boysen (2008) proposed a method and a heuristic procedure to manage and optimize a cross-docking platform; the discussed problem was the determination of a sequence of services for a set of inbound and outbound vehicles. As for approach B, Tsui and Chang (1999) dealt with the problem of the assignment of inbound/outbound vehicles to input/output docks referring to functional and operative characteristics of the terminal. The proposed procedure and model were drawn on Rong Zhu et al. (2009) in order to generalize the problem. This type of problem was discussed also by Aichelin and Adewunmi (2006), who proposed a discrete-event micro-simulation model, and by Bozer and Carlo (2008). Vis and Roodbergen (2008) tackled the problem of the optimal location of cargo units in a cross-docking warehouse by using a specific algorithm. Adewunmi and Aickelin (2008) dealt with the problem of the optimization of the picking process, while Liu and Takakuwa (2009) tackled the problem of the optimization of handling activities by using a simulation approach. Finally, Boysen (2010) proposed a procedure for scheduling inbound and outbound vehicles expressing the problem as a dynamic programming approach and solving it through heuristic procedures.

2. Approach to simulation of a UDC

The analysis and the study of the functionality of a logistic platform and, in particular, of a UDC can be dealt with by using simulation tools. The simulation approach allows to reproduce the system performances in a dynamic way, through the representation of its components and of existing interactions in terms of functional relations. Through the simulation, it is possible to get indicators, useful to measure the node performance, and to analyze the effects produced by changes in the node configuration by using "what if" techniques. Thus, the simulation is a tool to support decision-making during the system life cycle, from the planning to the sizing phase and to the following phases of management. A terminal system like a UDC can be simulated by using a discrete-event micro-simulation model. The system is represented in terms of activities that produce internal variations (events), while the entities, passing through the system, follow specific routes (processes). Therefore, the analyzed system is represented, in its temporal evolution, by using variables that change value in specific moments.

The model for the representation of activities is made up of 4 sequential steps:

- survey, to collect data related to the UDC structure and functionality;
- construction of a model, to highlight the functionalities and the operational bonds between the different areas of the platform;
- specification and calibration of probability functions related to the different functional components that contribute to the formation of the crossing time of the logistic node;
- implementation, to evaluate the reliability and reproducibility of the model.

A specific micro-simulation model has been implemented by using specialized software (WITNESS); the software has allowed to analyze the operational functionalities of a model created with base elements (parts, cars, buffers, vehicles, etc.). The micro-simulation approach will allow to evaluate the node performance in order to improve its efficiency, to optimize the relationship between the inbound and outbound freight flows, to assure speed and efficiency in the urban distribution and to limit the impacts on the city in terms of polluting emissions, space occupation and congestion.

3. Survey and data base structure

The survey, carried out to collect the useful data for the micro-simulation model of the UDC, has been based on direct investigations. There does not exist a codified methodological survey approach but recent literature has proposed some specific analyses that can contribute to define a reference methodology. Generally, the survey process is divided into five phases: planning, organization and preparation, execution, construction of an integrated informative system, elaboration of a summary framework. In this specific case, the survey has been aimed at collecting data for statistical analysis in order to carry out a functional study of a UDC. Two different types of survey have been conducted:

- a “macro” survey, aimed at the collection of general information on the node (functional and management structure, layout, infrastructural and superstructural resources);
- a “micro” survey, aimed at the collection of precise data related to the internal activities of the UDC (arrival management, unloading, sorting, handling, picking, loading).

The “macro” survey has allowed to define the functional model of the UDC. Instead, the “micro” survey has collected data about the management of the truck arrival in order to derive suggestions for the specification and calibration of probability density functions related to the arrivals distribution, the waiting time of trucks in the buffer and the service times. The survey, which has been referred to a period of one month in an Italian UDC, has allowed the construction of a large database containing information on 3.500 inbound trucks.

4. Functional model

Node representation shows the terminal functional components as well as their existing relations. It can be useful for the analysis and evaluation of the spatial, organizational and relational structure. The functional representation is in block diagrams, which show the sequence of operations in the node from the arrival to the departure of goods. In the case of a UDC, the survey has shown that the physical, organizational and management structure of the node is tightly connected with the considered supply chain, with the size of the treated load units (small items, pallets, etc.) and with the users. In general, according to such a logic, the structure of a UDC can be schematized in a sequence of six operational macro-areas. These areas can be grouped in three relevant zones: arrival, storage and consignment (Fig. 1).

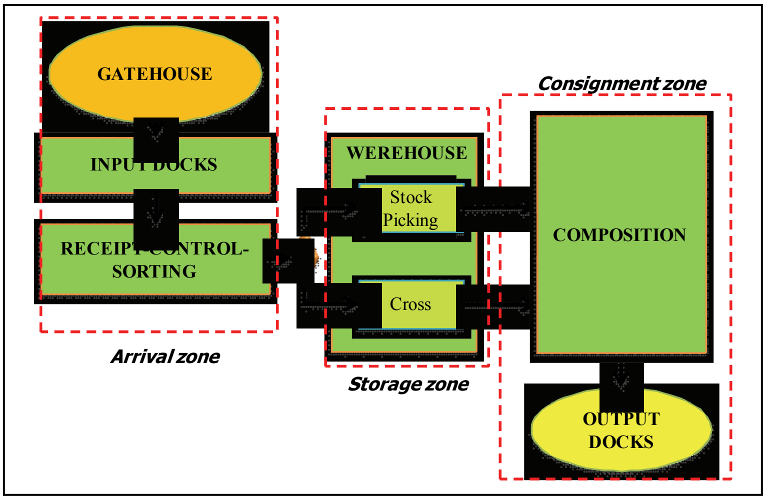

Fig. 1. Functional representation of UDC

It is possible to use a more detailed representation to describe the functionalities of each zone in relation to the activities which are carried out. This paper focuses on the reception zone and on the organization and management of truck arrivals.

Figure 2 shows the sequence of activities performed in the arrival zone in order to manage inbound trucks. After verifying the congruence of the quantity and type of goods transported by trucks, on the basis of their arrival order, the gatehouse assigns a dock and a serial number to the inbound vehicle. The dock is assigned according to the load typology, in order to optimize the subsequent operations of unloading and storage, while the serial number is assigned on the basis of the arrival schedule. Thus, trucks wait for service and, following their serial numbers, as soon as a gate becomes available in the assigned dock, they go to the platform and the unloading operations start. The unloaded Load Units (LU) are checked and, if they are suitable, they are sent to the warehouse, otherwise they are loaded on the origin truck, which leaves the dock at the end of this operation.

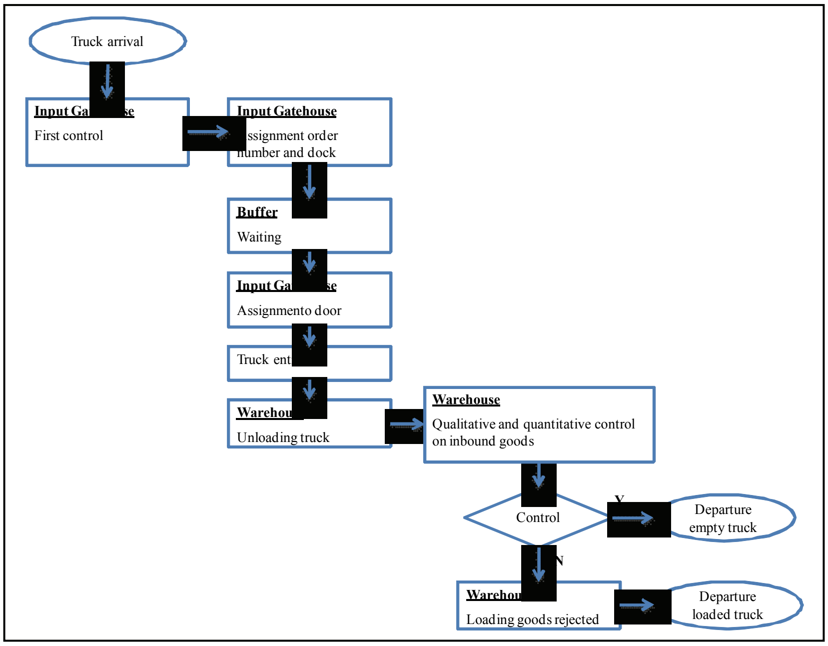

Fig. 2. Functional representation of arrival zone

5. Statistical analysis and probability functions

The statistical analysis of data has allowed the specification and calibration of probability density functions related to the arrivals of trucks, the time interval between two consecutive arrivals, the waiting time and the service time.

5.1. Arrivals distribution

The distribution of truck arrivals has been evaluated over a period of 27 days. On average, every day 129 trucks arrive at the UDC (standard deviation 24). The truck arrival is linked to the time slot of goods acceptance. On average, it is possible to observe about 7 arrivals in the time slot 0:00-5:00, 112 in the time slot 5:00-17:00, 1 in the time slot 17:00-21:00 and 8 in the time slot 21:00-24:00. Therefore, the arrival of trucks at the UDC is distributed throughout the day, showing a higher rate during working time. For this reason, four probability functions have been considered for the different time slots. Generally, the arrival of trucks to the UDC platform happens in a free way and represents a discrete phenomenon that can be dealt with through discrete distributions, such as Poisson distribution, Binomial or Negative Binomial (Pascal) distributions and Geometric distribution. For example, Figure 3 shows the trend of real and theoretical frequencies for the number of inbound trucks in the time slot 5:00-17:00.

It is possible to note that the Poisson distribution produces a much better fit for 0:00-5:00 and 17:00-21:00 time slots in accordance with the χ^2 test with a 5-percent significance level. Instead, for 5:00-17:00 and 21:00-24:00 time slots, the geometric distribution has been chosen to represent the real trend of arrivals numbers. In fact, the distribution fit is acceptable with a χ^2 test with a 5-percent significance level.

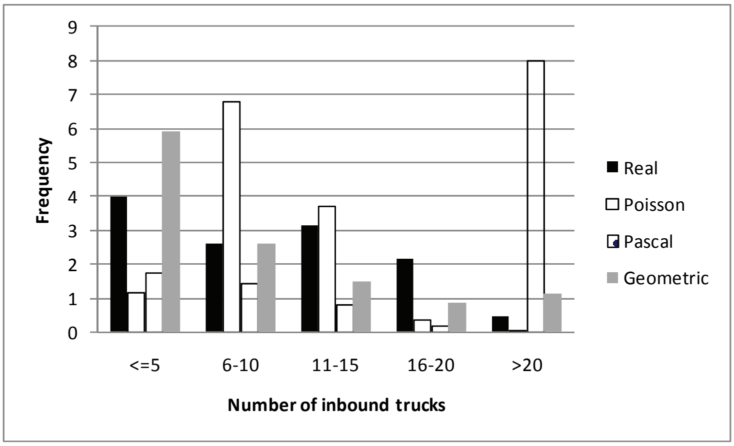

Fig. 3. Real and theoretical frequencies for arrivals of trucks

The inbound trucks are assigned to docks according to their load typology. On average, 26% of trucks are assigned to dock A, 23% to dock B, 7% to dock C, 24% to dock D and 20% to dock E.

5.2. Time interval between two consecutive arrivals

The time interval (I) between two consecutive arrivals is different for each considered time slot: early in the morning (0:00-5:00) the time interval fluctuates between 24 and 100 minutes; during the working time of the input gatehouse (5:00-17:00) the time interval is 4-7 minutes; finally, at night (21:00-24:00) the time interval fluctuates between 7 and 19 minutes. The analysis of the time interval has been carried out considering an exponential distribution and an Erlang distribution for different values of the characteristic parameter k. For example, Figure 4 shows the trend of real and theoretical frequencies for the time slot 5:00-17:00.

The goodness of fit for exponential and Erlang distributions has been verified by using a χ^2 test at different significance levels for different time slots. The results of the test have shown that the exponential distribution fits the data acceptably for every time slot.

5.3. Waiting time

In the analyzed UDC, the truck arrival is not managed following a FIFO (First In First Out) logic, but the entrance order depends on different factors, such as the type of goods and, as a consequence, the assigned dock where the unloading operations take place and the availability of a gate at the assigned dock. Thus, the waiting time of a truck is linked to both the arrival schedule and dock working. This management policy derives from the need to optimize the activities following the unloading (qualitative and quantitative control, sorting, storage); in fact, each dock is next to a specific area of the warehouse. For this reason, the analysis of data has been developed by differentiating docks (docks A, B, C, D, and E). The waiting time (T_W) variable has been analyzed by using two different continuous probability distributions: the exponential distribution and the Erlang distribution for different values of the characteristic parameter k. For example, Figure 5 shows the trend of real cumulative and theoretical frequencies for dock A.

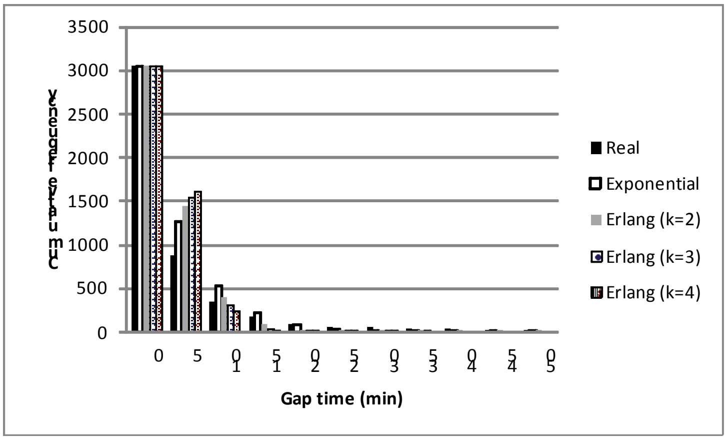

Fig. 4. Real and theoretical frequencies for *I* variable

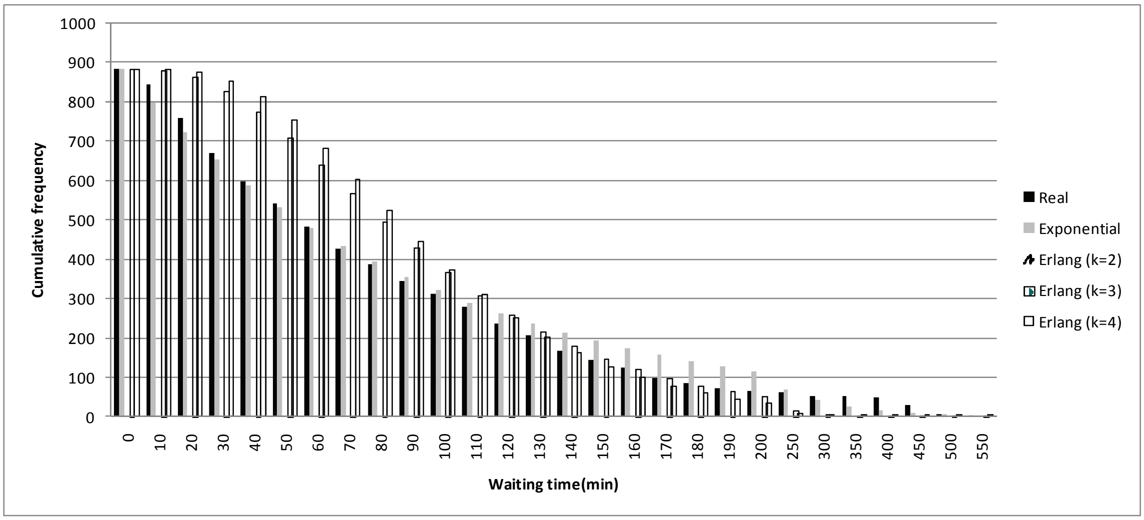

Fig. 5. Real and theoretical cumulative frequencies for T_W variable (dock A)

Table 3 shows mean, variance and standard deviation for T_w variable with reference to several operative docks. For an exponential variable, the mean is the scale parameter of distribution, while for an Erlang variable mean (μ) and variance (σ^2) are as follows:

$$\mu=k/Q;\ \sigma^2=1/(k\cdot Q^2) \qquad (1)$$

with k and Q as characteristic parameters of the distribution.

The comparison between real and theoretical frequencies and the result of the χ^2 test with 5-percent significance level allow to affirm that the fit of the exponential distribution is acceptable for all docks.

Table 3. Mean, Variance and Standard deviation for T_W variable

	Dock A	Dock B	Dock C	Dock D	Dock E
Mean (min)	98,73	95,27	76,75	113,60	121,73
Variance (min^2)	10.997,96	12.310,42	6.742,94	10.997,96	18.362,97
Standard deviation (min)	104,87	110,95	82,12	129,82	135,51

5.4. Service time

The service time (T_S) is the time necessary to:

- position and moor the truck at the assigned dock and gate;
- complete the unloading operations;
- execute the first control on inbound goods;
- load returned pallets on trucks;
- close semitrailer and unrig the gate.

The service time depends on the conditions of the load of the inbound truck; on the operational conditions of the dock where the truck is served; on the modalities used to unload goods (manual or with handling means); on the number of employees and means used at the dock to unload the truck and to carry out the controls; on the number of gates in the dock, etc. The study of the service time variable has been conducted with reference to Gauss and Gamma distributions for each operative dock.

For example, Figure 6 shows the trend of real and theoretical frequencies for dock B.

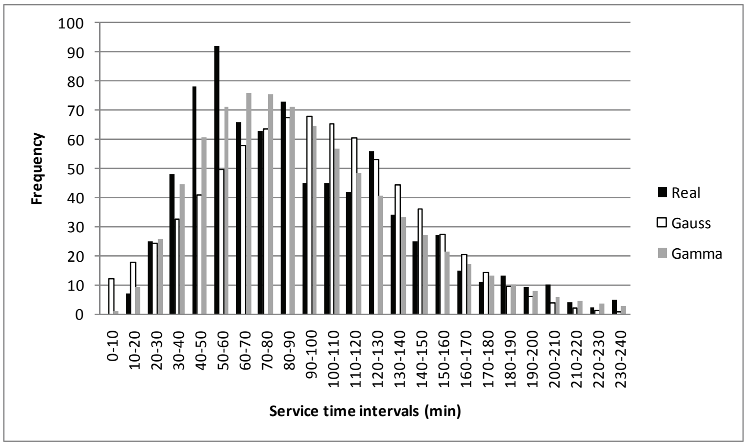

Fig. 6. Real and theoretical cumulative frequencies for T_S variable (dock B)

Table 4 shows mean, variance and standard deviation for service times for each operative dock. In a Gauss distribution, mean and standard deviation are characteristic parameters of the distribution, while in a Gamma distribution, mean and standard deviation are as follows:

$$\mu=a/\lambda;\ \sigma^2=a/(\lambda^2) \qquad (2)$$

with a and λ characteristic parameters of the distribution.

Table 4. Mean, Variance and Standard deviation for T_S variable

	Dock A	Dock B	Dock C	Dock D	Dock E
Mean (min)	66,15	92,03	86,61	101,23	112,74
Variance (min^2)	1.364,12	2.175,52	2.803,16	2.476,63	3.221,42
Standard deviation (min)	36,93	46,64	52,94	49,77	56,76

Real frequencies have a positive asymmetric distribution; for this reason, Gamma distribution has been chosen to describe the real trend of the service time variable. The comparison between real and theoretical frequencies and the result of the χ^2 test with 0,1-percent significance level justify this choice.

6. Validation analysis

In order to verify the soundness of the assumptions about the truck arrival, waiting time and service time, a discrete-event micro-simulation model has been constructed. The model has been implemented by using specialized software (WITNESS). In the analyzed UDC, a gatehouse and five input docks form the arrival zone. The docks are organized in gates for the unload activities (4 for dock A, 9 for dock B, 3 for dock C, 9 for dock D and 9 for dock E). Each dock is next to its relevant sector in the warehouse. The gatehouse is the centre for the arrivals management, with a buffer that can stock 300 trucks; the buffer is divided into five areas, one for each dock for truck berthing.

Table 5 shows the input parameters adopted in WITNESS to simulate the arrival and the management of inbound trucks in UDC.

Table 5. Input parameters adopted in WITNESS

Element	Variable	Type	Distribution	Parameters	
Truck arrivals in time slot 0:00-5:00	I	Stochastic	NegExp (μ)	μ=36,35 min	
Truck arrivals in time slot 5:00-17:00	I	Stochastic	NegExp (μ)	μ=5,66 min	
Truck arrivals in time slot 17:00-21:00	I	Stochastic	NegExp (μ)	μ=54,89 min	
Truck arrivals in time slot 21:00-24:00	I	Stochastic	NegExp (μ)	μ=13,39 min	
Gatehouse	Truck distribution	Stochastic	Random Percent (% dock)	A=26% B=23% C=7%	D=24% E=20%
Waiting Buffers	T_{Wm}	Deterministic	-	A: T_{Wm}=60 min B: T_{Wm}=65 min C: T_{Wm}=50 min	D: T_{Wm}=90 min E: T_{Wm}=100 min
Doors	T_S	Stochastic	Gamma (c=shape; k=scale)	A: c=3,21; k=0,048 B: c=3,89; k=0,042 C: c=2,68; k=0,031	D: c=4,14; k=0,041 E: c=3,95; k=0,035

The simulation has been carried out over a working day (0:00-24:00). The results of the application show that, out of 128 trucks arrived at the UDC, 7 arrived in the time slot 0:00-5:00, 112 in the time slot 5:00-17:00, 2 in the time slot 17:00-21:00 and 7 in the time slot 21:00-24:00. Figure 7 shows the trend of truck arrivals during the simulation period in comparison with the real trend of arrivals during an average working day.

Since the obtained trend is comparable to the real one, in fact in average the difference between the real and simulated arrivals in reference period is equal to 1,4%. The adopted probability functions allow to describe in an accurate way the phenomenon of truck arrivals at the UDC.

As regards the waiting time variable (Table 6), it is possible to observe that its mean value diverges from the one considered in the specification phase. This difference is lower than 16 % and derives from the high variability of the waiting time, which is tightly connected with the UDC operative characteristics that can change day after day according to the type of arrivals.

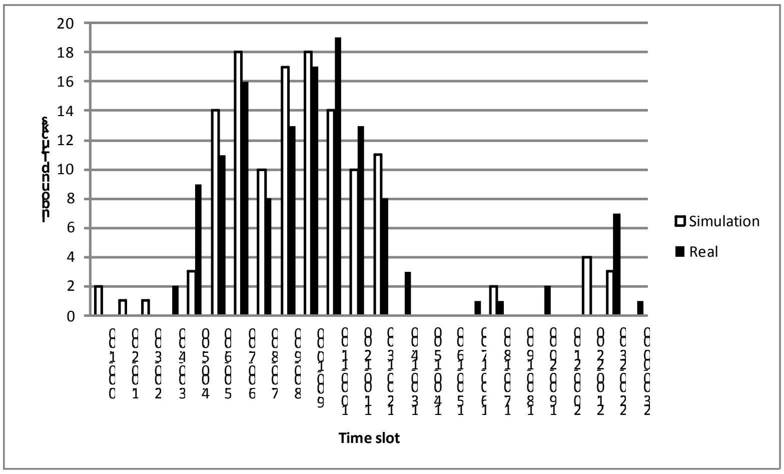

Fig. 7. Real and simulated number of inbound trucks

Table 6. Comparison between simulated and real waiting time

Dock	Average Simulated T_W (min)	Average Real T_W (min)	Δ%
A	108,04	98,72	8,63
B	109,39	95,26	12,92
C	73,18	76,74	-4,86
D	110,34	113,59	-2,95
E	104,54	121,73	-16,44

As for the service time variable, the simulation results show a difference of 7-15% in comparison with the real average service time (Table 7). It is possible to attribute this difference to the high variance that marked the real data.

Table 7. Comparison between simulated and real service time

Dock	Average Simulated T_S (min)	Average real T_S (min)	Δ%
A	61,81	66,15	-7,02
B	82,13	92,02	-12,05
C	75,11	86,61	-15,31
D	117,05	101,23	13,51
E	129,03	112,74	12,62

7. Conclusion

The simulation of the logistic activities of a UDC is a fundamental tool to optimize the activities of the same node and to evaluate its performance and impact on the city. The paper proposes a methodology to analyze the problems related to the functional organization of a UDC through a micro-simulation approach. The proposed analysis has allowed the specification and calibration of probability density functions of the times of node activities and, in particular, of the management of truck arrivals. The research results can be put on similar context (e.g. cross docking terminals) in particular with reference to service time variable. The others variables depend to the specific considered context and for this reason they must be calibrate appropriately. The development of the research is aimed at simulating the logistic activities of the whole UDC, at evaluating efficiency indicators and at verifying different operative solutions by using "what if" procedures.

8. Copyright

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